

IMAGE PROCESSING BASED TAILOR-MADE SOFTWARE PACKAGE FOR THE CONDITION MONITORING OF GRINDING WHEEL

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ABSTRACT

Condition monitoring of the grinding wheel is very significant in the industry as it plays a direct role in determining the final surface quality of the grounded components. But most of the current research in the field is focused on qualitative assessment of the grinding wheel condition. Application of machine vision and image processing are becoming more common in the manufacturing sector today. Various image processing techniques can be successfully utilized for distinguishing the loaded portion of the grinding wheel from the rest of the wheel. Here, we present the development and validation of an innovative software system based on image processing for evaluating quantitatively the percentage of grinding wheel loading. The software converts the RGB image captured using a USB microscope into the grayscale image that has pixel light intensity varying from 0 to 255. The high pixel intensity of the loaded chips in the grinding wheel is used for setting a threshold value for image segmentation (global thresholding). Based on the threshold value set, the software converts the grayscale image into a binary image of white and black pixels in which the black pixels corresponds to the loaded portion of the wheel. The percentage of wheel loading is determined as the ratio of black pixels to the total number of pixels. The results were validated with the equivalent Matlab® package and shows close agreement. This innovative, economical system has the capability of providing a reliable solution for the quantitative measurement of grinding wheel loading.

KEYWORDS: Grinding Wheel, Machine Vision, Image Processing, Image Segmentation, Grinding Wheel Loading & Condition Monitoring

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INTRODUCTION

Grinding is one of the most effective surfaces finishing method for almost all difficult-to-cut materials and alloys. The grinding wheel topography plays a major role in determining the precision of the grinding operation [1-2]. Several factors contribute to the changes in the surface topography of the wheel. Grinding wheel loading is one key phenomenon that limits the capability of grinding operations. The removed chips from the workpiece gets lodged between the abrasive grains of the grinding wheel, known as wheel loading, thereby diminishing the cutting capability and surface finish of the grounded components. Other adverse effects of wheel loading include the increase in cutting force and vibration. All of these factors, individually and in combination, tend to diminish the final surface quality considerably. By means of a wheel dresser, dressing operation is usually carried out to expose the fresh abrasive grains to the cutting surface and thereby enhance the performance of the grinding operation [3].

Downtime associated with the tool failure not only results in reduced productivity but can also end up in economic losses [4]. Condition monitoring of the grinding wheel, thus is highly significant. The operator working on the machine is mainly responsible for this task. The operator needs to periodically check the condition of the wheel and come up with the decision of carrying out the dressing operation. Even a skilled operator sometimes fails to assess the condition of the wheel when a new combination of materials, wheel and cutting parameters are involved. Moreover, as we are swiftly progressing into an era of fully automation, equipped with unsupervised CNC machines, an automated technical solution is necessary to address the aforementioned issue.

Monitoring of the grinding process can be carried out in both online and offline modes. By analyzing the hydrodynamic pressure of the grinding fluid used during the grinding process, the surface topography of the wheel can be assessed [5]. But the highly turbulent flow of the cutting fluid as the grinding progresses may cause difficulties. Also, this cutting fluid causes a serious limitation for online monitoring systems. Most researchers were concentrated on offline monitoring systems, where a variety of sensors found in applications. Liao et al investigated the condition of the grinding wheel using acoustic emission sensors and wavelet transform was used for analyzing the AE signals [6]. Mokbel et al also used the AE sensors, but with a difference of using Fast Fourier transform (FFT) for analyzing the AE signals [7]. Humphreys et al applied field programmable gate array (FPGA) for acquiring and processing vibration signals, and applied feature extraction techniques for the condition monitoring [8]. However, high expertise required is one of the major limitations associated with this approach. Kim et al applied eddy current sensor and laser displacement sensor for monitoring the wheel loading and dressing operation [9]. Nakai et al applied Artificial Neural Network (ANN) for modeling and prediction of the grinding wheel wear [10]. AE and cutting force signals acquired during the grinding process were used for training and validating the neural models. ANN takes care of the high non-linear relationship between the wheel wear and acquired signals, which may not be possible with traditional mathematical models. Above all, cost associated with the equipment for the above techniques are relatively high, which is the main drawback.

Machine vision technology, with the recent advances, is becoming an extremely powerful tool in the monitoring of various machining processes [11-16]. Being exceptionally fast in processing the image and because of its high flexibility, manufacturing industries nowadays benefit a lot from image processing techniques [17-19]. Lachance et al made use of CCD camera to capture the wheel images and applied image processing techniques to extract the wear flat area [20]. Chang et al performed the wheel contour measurement of form grinding wheels used for micro drill fluting using machine vision system [21]. Feng et al utilized the edge detection based on Sobel operator for extracting the wheel wear data [22]. Adibi et al used the image processing toolbox of Matlab for the measurement of wheel loading in the CBN vitrified grinding wheel. Images were captured using a microscope and edge detection techniques were applied for obtaining the loading information [23]. Fan et al used CCD camera and binarization technique for evaluating the wear of the grinding wheel.

The uniqueness of this proposed method from the above-mentioned researchers is the development of a software package based on image processing for measuring the grinding wheel loading quantitatively. Portable USB microscope with a magnification of 20X captures the images of the wheel topography, and thresholding based edge detection technique performs the image processing. The results obtained from the software developed were validated with the results from Matlab.

OPTICAL PROPERTIES OF THE GRINDING WHEEL LOADED CHIPS

Machine vision and image processing is progressively becoming a powerful tool in the monitoring of manufacturing processes. The optical properties of the chips, which get lodged between the abrasive grains of the grinding wheel, are a reliable tool for distinguishing the loaded portion from the rest of the grinding wheel. Since grinding is most commonly used as a final finishing process, the chips that get removed from the workpiece during the grinding operation is highly reflective and appears brighter (see Figure 1).

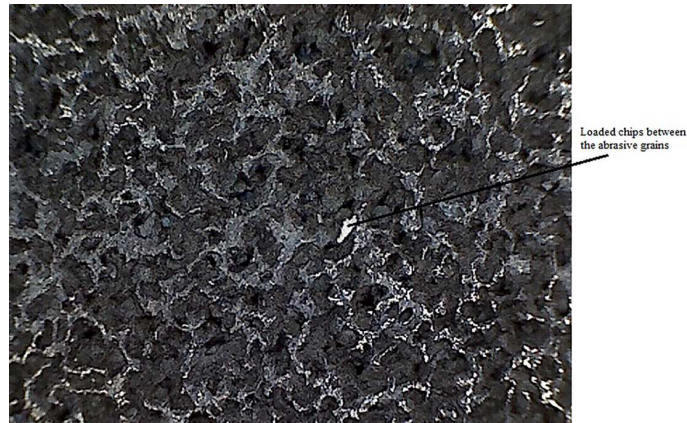


Figure 1: The Grayscale Image of the Loaded Grinding Wheel Captured with a Magnification of 25x

The captured image of the grinding wheel when converted to grayscale image, have pixel light intensity values ranging from 0 to 255, where 0 corresponds to pure black and 255 corresponds to pure white. Because of the high reflectivity of the removed chips from the workpiece, the loaded portions of the grinding wheel have comparatively high pixel intensity values. Image processing technique can be applied for extracting this loaded portion of the wheel and thereafter for quantitatively estimating the percentage of wheel loading. Image segmentation using a properly selected higher threshold value can be used for distinguishing the loaded portion from the rest of the grinding wheel.

IMAGE SEGMENTATION

Image segmentation is one of the most essential steps in image processing. Image segmentation fundamentally divides an image into segments based on certain features or attributes. Applications of image segmentation involve object recognition, boundary representation, template matching, etc. The various segmentation techniques include threshold based, edge-based, region based and clustering techniques. The most common and the very basic is the threshold based segmentation technique. In the grayscale image, each pixel has a value that carries the light intensity information alone, which can have values ranging from 0 to 255. In threshold technique, based on a certain threshold value of the pixel light intensity, the grayscale image is converted to the binary image having black and white pixels. Each pixel value of the image is compared with the selected threshold value. If the pixel value is greater (or smaller) than the threshold value, that pixel is converted to the white pixel and the opposite to black pixel. In this research work, black pixel represents the background or the abrasive grains and white pixel corresponds to the loaded portion of the wheel, where the chips get lodged.

The most challenging task in threshold based segmentation is the selection of a proper threshold-value. Threshold values can be selected manually or else a few algorithms are available for automatically selecting the threshold

value. Otsu's method is one such algorithm, which automatically selects a threshold value and thereby performs the thresholding operation. A more reliable approach for this research work is to select a threshold value based on the histogram of the gray-scale image. A histogram is a graphical representation of gray level intensities and its frequencies. X-axis represents the intensity of the gray level and Y-axis represents the frequency of the gray level intensities. By analyzing the histogram of the fully dressed wheel (unloaded wheel), as shown in Figure 2, it is clear that the gray level intensities below 170 correspond to the unloaded portion of the wheel. When the shiny chips get lodged between the bonded abrasive grains, the gray level intensities of those pixels representing the loaded portion will be higher than 170. As a result, by selecting a threshold value of 170, all the pixels with values up to 170 is converted to black representing the abrasive grains of the wheel and the pixels with values above 170 is converted to white representing the loaded portion of the wheel. The ratio of the number of white pixels to the total number of pixels estimates the percentage of grinding wheel loading.

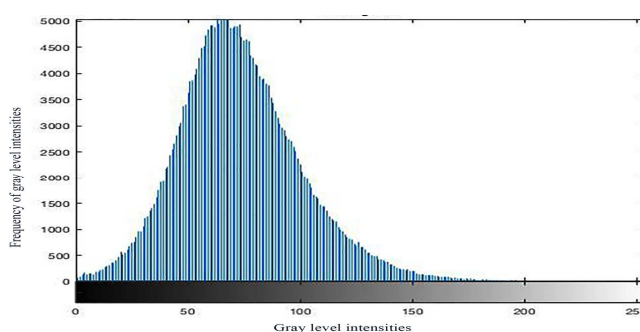


Figure 2: Histogram of the Fully Dressed Wheel

DEVELOPMENT OF SOFTWARE PACKAGE

Numerous software packages like Matlab, Labview, etc., can carry out image processing and image analysis. But these packages are expensive and complex, and sometimes require coding. Quantitative measurement of the percentage of grinding wheel loading using the above-proposed principle requires very few among the large set of image processing techniques available. A custom-made software package that can perform the required processing and analysis function, which this application demands, will be of great potential, particularly for industries. Following are the various steps to be performed for evaluating the wheel loading percentage.

Step 1: Uploading the captured image of the grinding wheel for image processing.

Step 2: Converting the uploaded RGB image to grayscale image.

Step 3: Setting the threshold value.

Step 4: Obtaining the binary image after image segmentation based on the threshold value set.

Step 5: Obtaining the percentage of grinding wheel loading based on the ratio of white pixels to the total number of pixels.

The programming language used for developing the software package was C#, which is one among the several .NET programming languages. Microsoft visual studio was used as a platform for coding and the package was developed as a Microsoft Windows- based application software. The graphical user interface (GUI) of the software will look as shown in Figure 3.

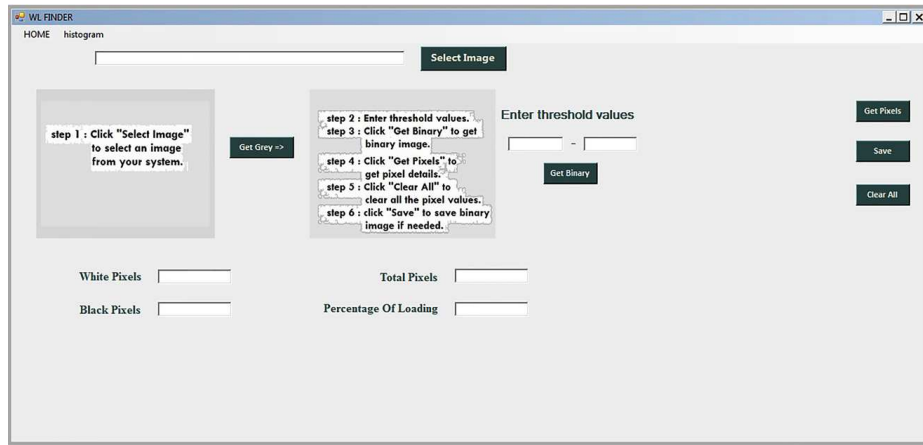


Figure 3: Graphical User Interface of the Developed Software

EXPERIMENTAL SETUP

Cylindrical grinding machine with Silicon Carbide grinding wheels was used for conducting the experiments. The grinding wheel considered was of 200mm diameter and 30mm width. Workpiece material used for grinding operation was High Carbon High Chromium Steel. Grinding wheel images were taken with a magnification of 25x and using Veho USB microscope. Since the magnification used was 25x, the field of view was small. Illumination plays a significant role in machine vision systems and the end results largely depend on proper and constant illumination. Constant illumination was ensured using the ring of LEDs provided on USB microscope. The brightness of the LEDs can be adjusted using a knob provided on microscope thereby ensuring constant illumination. Cutting parameters and specifications of the grinding wheel are given in Table 1, and Figure 4 illustrates the experimental setup.

The grinding wheel is initially dressed and subsequently, the image is taken with a magnification of 25x. The histogram of the image is obtained and examined to set the threshold value as discussed in the previous section. In this case, the threshold value selected for differentiating the loaded portion of the wheel is 170. After capturing the image of the fully dressed wheel, grinding operation is performed. The image of the loaded grinding wheel is again taken after 40 passes for further processing and evaluation of wheel loading.

Table 1: Specification of Grinding Wheel and Cutting Parameters

Grinding Wheel	Silicon Carbide
Grinding wheel diameter	500 mm
Speed of the grinding wheel	205 rpm
Table speed	.140 m/min
Depth of cut	.02 mm
Workpiece	High Carbon High Chromium Steel
Microscope	Veho USB Microscope
Magnification	25x



Figure 4: Experimental Setup

RESULTS AND DISCUSSIONS

The brightness of the chips, which gets lodged between the abrasive grains, as discussed in Section 3 is utilized to extract the loaded portion from the rest of the wheel. The gray scale image of the fully dressed wheel is shown in Figure 5. An analysis of the histogram clearly indicates that the dressed portion of the wheel corresponds to a threshold value ranging from 0-170. The chips that get loaded during the grinding operation have a threshold value above 170 because of its brightness and shiny appearance. Thus a threshold value of 170 is utilized for image segmentation. The captured image of the loaded grinding wheel, after 40 passes of grinding operation on HCHCR Steel, as shown in Figure 1, is uploaded to the developed software and a threshold value with the range of 0-170 is set. The software package analyses the grayscale image of the uploaded image and converts all the pixels in the range of 0-170 to black pixels and above 170 to white pixels, thereby generating a binary image. The white pixels represent the lodged chips between the abrasive grains. The graphical user interface of the software after setting the threshold value and obtaining the binary image is as shown in the Figure 6.

The percentage of wheel loading can be obtained by calculating the ratio of the number of white pixels to total number of pixels. By clicking on the tab “Get Pixels”, the software will evaluate the ratio and display the percentage of loading. The screenshot of the developed software package after processing and analyzing the image is shown in Figure 7. In this case with the threshold value of 170, the number of white pixels are 7632, the total number of pixels is 307200 and the percentage of the wheel loading is 2.484375. Results after image processing and analysis are given in Table 2.

Table 2: Percentage of Wheel Loading Obtained after Image Processing and Analysis

Number of White Pixels	7632
Number of black pixels	299568
Total number of pixels	307200
Percentage of wheel loading	2.484375

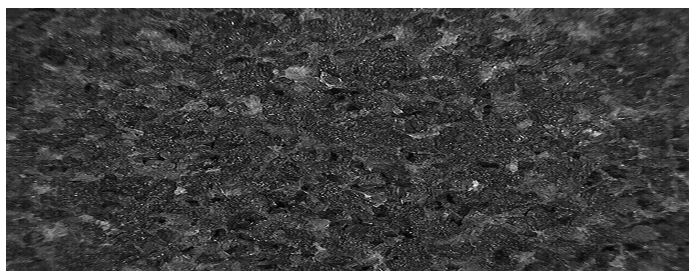


Figure 5: The Grayscale Image of Fully Dressed Wheel with a Magnification of 25x

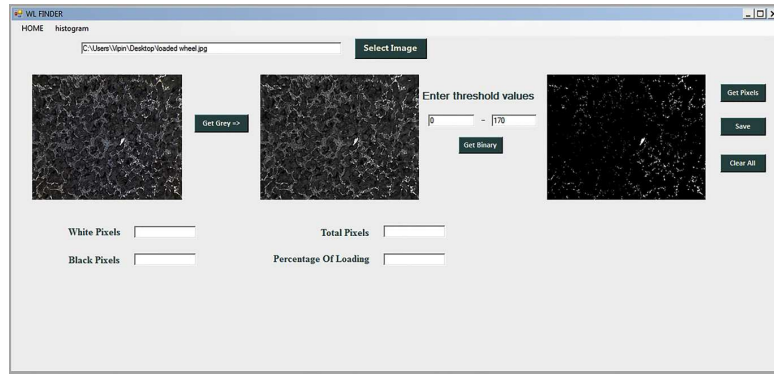


Figure 6: GUI of the Software after Obtaining the Binary Image

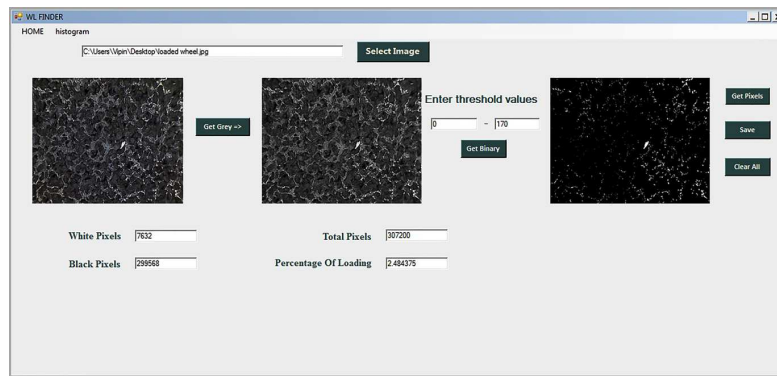


Figure 7: GUI of the Software after Obtaining the Percentage of Wheel Loading

VALIDATION OF DEVELOPED SOFTWARE PACKAGE

Matlab is one among the most commonly used software for image processing and analysis. The results from the developed software are validated with the results from Matlab. Based on the various stages of image processing and analysis as discussed in Section 4, a Matlab program is developed and executed. The image of the loaded grinding wheel as shown in Figure 6 is fed as input into the Matlab. With the same threshold value of 170, the resulting binary image and the percentage of wheel loading is obtained from Matlab. The resulting binary image from Matlab and developed software is shown in Figure 8. The percentage of wheel loading obtained from Matlab is 2.4775, which is in close proximity to the results obtained from the developed software package, which is 2.484375. A comparison of the results obtained from Matlab and developed software is given in Table 3.

Table 3: Comparison of the Results obtained from Matlab and Developed Software

	Matlab	Software Developed
Number of white pixels	7611	7632
Number of black pixels	299589	299568
Total number of pixels	307200	307200
Percentage of wheel loading	2.4775	2.484375

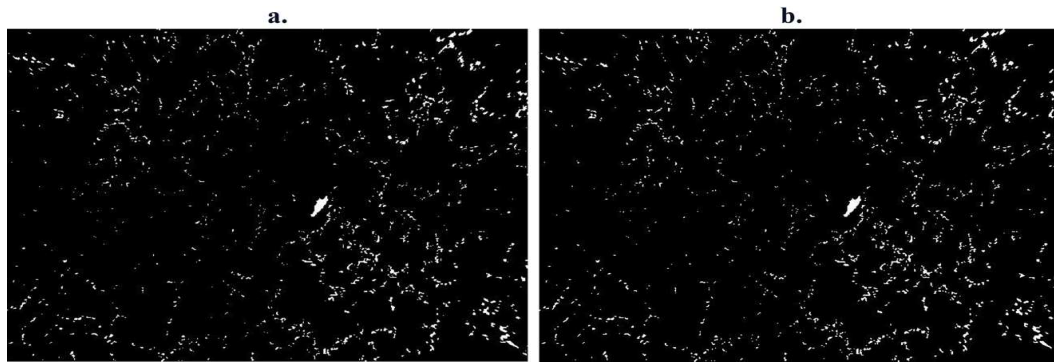


Figure 8a: The Binary Image Obtained from Matlab
b. The Binary Image Obtained from the Developed Software

CONCLUSIONS

Experimental results demonstrate the feasibility of evaluating the percentage of wheel loading using image processing techniques. Image segmentation with thresholding seems to be satisfactory for the quantitative measurement of wheel loading. A suitable threshold value for performing the image segmentation can be selected after analyzing the histogram of the fully dressed wheel.

The tailor-made software which performs the required image processing and analysis functions, is an alternative to complex and expensive software packages available for image processing. The processing and analysis time required for the software is between 5-8 seconds, which is reasonably fast. The validation of the results from the developed software with the Matlab shows that the developed software is reliable and effective for the quantitative measurement of wheel loading.

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